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SUSAN Y. SOONG
CLERK, U.S. DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA

**IN THE UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA**

UNITED STATES OF AMERICA,

Plaintiff,

v.

PACIFIC GAS AND ELECTRIC
COMPANY,

Defendants.

No. C 14-00175 WHA

SUPPLEMENTAL AMICUS BRIEF

Petitioner Andrew Paul Kangas hereby submits the following supplemental amicus brief in the matter of Pacific Gas and Electric Company (hereafter PG&E) in the United States Northern District of California, San Francisco Division. Paul Kangas is a PG&E shareholder.

Petitioner draws the Court's attention to the threat of a nuclear meltdown posed by PG&E's Diablo Canyon Nuclear Power Plant Units #1 and #2. Specifically to the expert testimony of Nuclear Engineer Arnold Gundersen given to CPUC on January 27, 2017 and to testimony has been given by onsite Nuclear Regulatory Commission Inspector Dr. Michael Peck. The testimony of the two experts coincides with the United States Nuclear Regulatory Commission's requirement that PG&E conduct scheduled testing of the welds throughout the reactor's stainless steel pressure vessel and piping, and a metallurgical examination to determine the deterioration due to Neutron Embrittlement.

1 Petitioner requests that the Court issue a temporary injunction to stop the reactor from
 2 power operation until an independent entity conducts adequate and public testing of the reactor's
 3 potential for safe operation.

4 This supplemental filing explains to the court two types of severe metallurgical dangers
 5 that PG&E is ignoring at the Diablo Canyon Nuclear Facility.

6 The first danger is referred to in the profession of nuclear power and regulation as
 7 "Embrittlement" that can cause the stainless steel in nuclear reactors to break causing a nuclear
 8 accident.¹ Since 2010 PG&E has operated the reactors without adequate shut down procedures
 9 in the event of an earthquake along the fault line the reactor was built on.

10 "PG&E and the NRC are ignoring the severely degraded condition by allowing Diablo
 11 Canyon Unit #1 to operate."² "It is disturbing that the alleged 'solution' created by the
 12 NRC and Pacific Gas and Electric to protect Unit 1 against its increasing neutron
 13 embrittlement, is simply to create administrative controls that require Diablo Canyon
 14 atomic reactor operators...[in an emergency]... to raise the temperature prior to raising
 15 the pressure." "Rather than fix its aging embrittled reactor vessel, PG&E's strategy for
 16 Diablo Canyon Unit 1 is to repeatedly modify its mathematical calculations."³

17 Nuclear fuel, the metallic element uranium (U-235), refined and used in a nuclear power
 18 plant, undergoes a chain reaction which emits a tremendous number of neutrons per second as
 19 the atoms of uranium in the fuel split into other, lighter, radioactive elements.

20 Energy in uranium is released as heat, to generate steam, to generate commercial
 21 electricity. The quantity of the neutrons moving through the fuel elements and through the
 22 stainless steel structure of the reactor vessel holding the uranium fuel is known as the "Neutron
 23 Flux."

24 Embrittlement is a metallurgical change which occurs in the stainless steel of the reactor
 25 as the result of neutrons colliding with individual atoms of the metal comprising the structure
 26 holding the fuel elements known as the reactor "core." Reactor embrittlement after 25 years of
 27 operation can cause an atomic reactor to shatter like glass creating what the Nuclear Regulatory
 28 Commission (NRC) calls a Class 9 Accident, which is the worst nuclear catastrophe

26 ¹ "Irradiation Embrittlement and Creep in Fuel Cladding and Core Components," Published
 27 January 1, 1973, ISBN: 0-7277-5117-4.

28 ² Arnie Gundersen, Fairewinds, testimony to CPUC, January 27, 2017, Appendix A, page 4.

³ Arnie Gundersen, Fairewinds, testimony to CPUC, January 27, 2017, Appendix A, page 12.

1 acknowledged by the NRC.”⁴

2 Embrittlement also affects the stainless steel of the pressure vessel⁵ and its welds, above
3 the core, the piping which transports cool water into the core, and the high pressure stainless
4 steel piping that transports steam out of the core to the generator that transforms this steam into
5 commercial electricity.

6 The two reactors at Diablo Canyon were designed with a predicted safe service life of 25
7 years under full power operation. Unit #1 went into full time service on May 7, 1985. Unit #1
8 has been in actual full power operation for approximately 87% of the current period (33 years)
9 according to PG&E. That makes twenty nine years at full power. The power of the neutron flux
10 affecting the core can be judged when we realize that the energy released at any given instant is
11 equal to 3 million horsepower. The originally predicted 25 years for safe operation for Units #1
12 and #2 was a profession-wide estimate based on two decades of nationwide practical nuclear
13 power experience. The State of California has now scheduled the reactors to be decommissioned
14 in 2025.

15 Metallurgical embrittlement is the reason the operation of a nuclear power plant is limited
16 and it must be monitored for safety. Since 2001 nuclear industry experts such as Odette and
17 Lucas continue to acknowledge that the service life of old atomic reactors is limited by
18 embrittlement.⁶ The petitioner, Paul Andrew Kangas offers this amicus brief to the court as this
19 important fact is not common public knowledge.

20 When Unit #1 was built small metal samples were positioned in the reactor. These are
21 referred to as “coupons.” These samples were intended to be analyzed on a schedule in order to
22 compare the actual condition of the material of the reactor with the predicted state of
23 deterioration.

24 ⁴ Arnie Gundersen, Fairewinds, testimony to CPUC, January 27, 2017, Appendix A, page 3 of
25 24.

26 ⁵ “Industry Practice for the Neutron Irradiation Embrittlement of Reactor Pressure Vessels in
27 Japan.” Norimichi Yamashita, Masanobu Iwasaki, Koji Dozaki, Naoke Soneda Journal of
28 Entineering for Gas Turbines and Power 132 (10), 102919, 2010.

⁶ Arnie Gundersen, Fairewinds, testimony to CPUC, January 27, 2017, Appendix A, pages 12-
13.

1 The reactors at Diablo Canyon are exceptional among nuclear power plants because
 2 being in California they are subject to large, sudden earthquakes. To save costs PG&E initially
 3 tried to construct them with its own company engineers. PG&E's practice of cutting corners left
 4 Unit #1 with a weakened pressure vessel due to improper material in its welds. The NRC
 5 subsequently relaxed its standards for welds to accommodate PG&E's error regarding Unit #1's
 welds.

6 Pacific Gas & Electric abandoned the schedule of analyzing the "coupons" in 2003. Unit
 7 # 1 reached 70% (17 years) of its safe design life in 2003. It is criminally negligent of PG&E to
 8 forego metallurgical testing thus failing to assess Unit #1's actual state of deterioration. Since
 9 2003 PG&E has intentionally hidden the state of deterioration from the public.

10 Units #1 and #2 at Diablo Canyon are among the biggest reactors ever built. A single
 11 reactor continuously produces a gigawatt (more than a billion watts) or more of electric power.
 12 Embrittlement makes it difficult to safely turn off, or to "shut down," a nuclear reactor in the
 event of sudden emergencies.

13 A nuclear reactor can never be completely "turned off" unless all the radioactive fuel rods
 14 are physically removed from its core. What is not halted during "shut down" is the spontaneous
 15 decay in the fuel and the continuing, albeit reduced, chain reaction caused by neutrons which are
 16 not captured by the 'Control Rod Assembly.' Active reactors are only slowed down by lowering
 17 a large assembly of neutron absorbing material into the core to halt much of the chain reaction.
 18 The amount of residual energy being released in the core after a "shut down" is in fact still
 19 enormous, on the order of 250,000 hp.⁷ This equals the output which the reactor of a 100,000
 20 ton navy nuclear supercarrier generates at full power and at top speed, (35 knots). During and
 21 after a "shut down" cooling water must continue to be pumped into the core to keep the residual
 22 energy of the fuel from melting the stainless steel of the reactor. Following an earthquake such
 action may cause the deteriorated core to fracture causing a meltdown.

23 The very hot stainless steel of a very hot reactor core, operating at full power is 1800
 24 degrees Fahrenheit, this must be forced to cool off during an emergency at the same rate at which
 25 the "shut down" occurs, the rate of which may not remain under control of the plant operator
 26 during an emergency shut down. During a rapid shut down after an earthquake, severely
 27 embrittled stainless steel reactor core is subject to cracking or shattering just as a piece of glass

28 ⁷ http://www.radioactivity.eu.com/site/pages/Reactor_Shutdown.htm

1 is, through rapid cooling.

2 An operator attempting to introduce cool water into a reactor core during a rapid shut
3 down event must use entirely different calculations for heat transfer, flow rate, and temperature
4 than the normal situation while the reactor is running normally at full power. An operator
5 mistake following an earthquake will cause a catastrophe. The faster the operator tries to shut
6 down a nuclear reactor the more likely the core will shatter resulting in a catastrophe like
7 Fukushima, Japan that resulted in severe local and global radiation contamination.

8 In the U.S. nuclear industry the first reactor ordered decommissioned due to the danger of
9 embrittlement was the Yankee Rowe Power Plant, in Rowe Massachusetts.⁸ Built in 1960,
10 Yankee Rowe went into an emergency shut down in 1992 after being struck by lightning. Upon
11 inspection, the deterioration of the core's metal was so much a danger that the plant was
12 permanently closed.

13 The Yankee Rowe plant went into an emergency shut down with no other associated
14 dangers. An earthquake at Diablo Canyon would cause additional dangers. Petitioner asks the
15 court to order PG&E to answer the embrittlement question by hiring a laboratory selected by the
16 court and which is completely independent from any dependency on PG&E.

17 Any size earthquake at Diablo Canyon could cause potential physical damage to intricate
18 components. Pumps could fail, high pressure steam pipes break loose, and control panels suffer
19 damage. Any damage at all, given the core's present condition can lead to a miscalculation
20 during the "shut down." In testimony before the California Public Utilities Commission (January
21 27, 2017) nuclear engineer Arnold Gundersen testified as to the extreme danger:

22 "[T]he earthquake would cause a sudden emergency shutdown that could defeat most
23 safety systems, cause control room instruments to become unreliable because of
24 "instrument chatter"... and, thus provide the control room operators with little or no
25 accurate data about the temperature and pressure in the reactor."⁹

26 Further, in 2012, a highly respected employee of the Nuclear Regulatory Commission,
27 Dr. Michael Peck, used a rare procedure at the NRC to challenge PG&E's license to operate
28 Diablo Canyon, "due to erosion of regulatory margins" under the jurisdiction of the NRC. Dr.

26 ⁸ Arnie Gundersen, Fairewinds, testimony to CPUC, January 27, 2017, Appendix A, page 19.
27 "One U.S. reactor was so seriously embrittled (Yankee Rowe) that its owner decided to
28 permanently terminate its operating license and shut the reactor down..."

⁹ Arnie Gundersen, Fairewinds, testimony to CPUC, January 27, 2017, Appendix A, pages 10-11.

1 Peck's statement September 23, 2014 was:

2 "Beginning in 2012, I used the Nuclear Regulatory Commission non-concurrence and
3 differing professional opinion (DPO) process to raise nuclear safety issues at Diablo
4 Canyon... the DPO asserted that PG&E continues to operate the Diablo Canyon reactors
5 outside of the bounds as defined by the NRC Operating License, Any operation outside
6 of the design basis challenges plant safety due to erosion of regulatory margins."

7 This challenge by a highly regarded engineer called on the NRC to reevaluate the
8 physical structure in light of the actual damage caused to the Fukushima reactors during the 2011
9 earthquake. Mr. Peck's DPO in 2012 was made two years past the projected maximum safe
10 operating period of Diablo Canyon based purely on predicted metallurgical deterioration.

11 PG&E's continued operation of the Diablo Canyon nuclear reactor is typical of the
12 utility's distorted public relations campaign and is creating a danger to the public in pursuit of
13 profit.

14 Instead of promptly performing metallurgical testing to answer this safety question,
15 following Fukushima and instead of engaging and using sound engineering to put real
16 procedures into effect, PG&E has established no new safety measures since 2010.

17 This time period corresponds to the explosion in San Bruno California on September 9th,
18 2010, where PG&E engaged in willful contempt for public safety. In that case PG&E lied about
19 both the condition of Line 132, and the pressure it was being subject to. PG&E was unable to
20 shut off the gas flaming into the Crestmore Neighborhood for 45 full minutes. This erupting
21 flame blocked fire fighters and rescue into the neighborhood and resulted in the destruction of
22 dozens of homes. PG&E could not shut off the gas supply.

23 In the 2018 Camp Fire which recently totally destroyed the community of Paradise
24 California, PG&E again was unable to control the machinery of its power production. PG&E
25 could not shut off the electric power during a high wind event, and the company now has no
26 certain way to shut down the reactors of its Diablo Canyon nuclear power plant.

27 The company known as "PG&E the Utility" became a non-responding shell entity on
28 June April 6th, 2001 when the company known formerly as "Pacific Gas and Electric Company
split into two entities for the specific purpose of manipulating the California Energy Market
during a temporary price increase in domestic natural gas, and then to escape from responsible
regulation. Now the "Utility" is again asking for bankruptcy protection, while its twin, "PG&E
the Holding Company" has the actual profits made over time in its accounts and holds title to the
properties used by PG&E the "Utility", including the nuclear power plant at Diablo Canyon.

Petitioner Paul Kangas suggests strongly to the Court that PG&E, "The Utility" is

1 nonfunctional under the original terms of its granted monopoly, which was granted by the State
2 of California to the former single corporate entity "Pacific Gas and Electric Company". This is
3 the direct cause for the end of reasonable safety and maintenance of the power grid which has
4 inflicted harm on the people of California. The revenue from the Power Plant at Diablo Canyon
5 is a matter now in the bankruptcy proceeding. The Court has the opportunity to act as a good
6 manager and issue a temporary injunction.

7 The second metallurgical danger in Unit #1 is also caused by neutron flux embrittlement.
8 Quoting from the NRC:

9 "Several technical issues must be addressed as the vessels operate over long periods of
10 time... Reactor operation generates subatomic particles called neutrons. Some of these
11 neutrons hit atoms in the steel as they leave the core. These neutron impacts... make
12 steel brittle and less able to handle the stresses of operation... The percentage of copper
13 and nickel in the steel (the welds) also affects how... a vessel becomes embrittled."

14 The stainless steel pressure vessel of Unit #1, unlike that of Unit # 2, was constructed
15 with a faulty welding material. The welding "sticks" contained excessive copper. This flaw
16 came to the Public's attention in 1998 when the NRC issued an order to PG&E to produce weld
17 inspection data in order to determine if the pressure vessel of Unit #1 was unsafe to operate.
18 PG&E used the wrong material to weld stainless steel during the construction of Unit #1.

19 The pressure vessel must withstand 1000 to 2000 pounds/per/square inch of steam
20 pressure at 1800 degrees Fahrenheit when the reactor is operating at full power. The weaker
21 than designed welds in Unit #1 have been "temperature cycled" and "pressure cycled" each time
22 the reactor has started and shut down over the 33-year operation of Unit #1.

23 The NRC requires a complete ultrasound inspection every ten years of those welds made
24 in the construction of a pressure vessel in a nuclear plant. However, according to a noted
25 educator and nuclear engineer Arnie Gundersen of Fairewinds Energy, PG&E obtained a waiver
26 from the NRC in 2014. Thus, PG&E is in this second matter also acting with criminal negligence
27 to hide the actual condition of the pressure vessel from the public, the California Public Utilities
28 Commission, and The California State Lands Commission.

Arnie Gundersen, provided this testimony to the CPUC on January 27th, 2017.

"While Diablo Canyon was in its 20-year construction period... More than 100 atomic
reactors were canceled after contracts were created, due to escalating construction costs
and delayed and unmanageable construction schedules. .. Diablo Canyon('s) cost
overruns were so significant that PG&E became an example of what could go wrong
during nuclear power plant design and construction. While the majority of utility
executives throughout the country began to recognize the enormous costs and risks of

1 building new nuclear power plants, and therefore chose to terminate construction in order
 2 to minimize passing ever increasing costs on to their ratepayers, PG&E forged ahead.
 3 PG&E passed the rapidly escalating Diablo Canyon cost overruns on to PG&E
 4 ratepayers. Of the quagmire of issues associated with the 20-year construction period of
 5 the Diablo Canyon the first serious mistake that PG&E made at the very onset of its
 6 design process during the mid-1960s was the decision to use its own staff to engineer the
 7 design and construction of the atomic power reactors at Diablo Canyon, rather than seek
 8 the skills of an engineering firm fully experienced in... the complex engineering
 necessary for atomic reactor construction projects. ...The inexperienced PG&E nuclear
 power design and construction engineering staff made errors at Diablo Canyon that
 created defects that impact its current operation. ... These flaws and defects include, but
 are not limited to, PG&E's ... Use of the wrong welding material for the nuclear reactor
 itself..."

9 The NRC requires a complete ultrasound inspection every ten years of the welds made in
 10 the construction of a pressure vessel in a nuclear plant. However, in his testimony to the CPUC
 11 on January 27, 2017 Arnie Gundersen states that after its 25 year safe design limit had already
 12 lapsed, and following Fukushima, PG&E obtained a waiver from the NRC to ignore and suspend
 the full ultrasound inspection of Unit #1.

13 "Even though Diablo Canyon began operation in 1985, the atomic reactor for Unit 1 was
 14 purchased approximately 20 years earlier and delivered to the Diablo Canyon Site in
 15 1973. The Diablo Canyon reactor vessel was one of the first ever manufactured for the
 16 nuclear power industry, by a company with no previous experience manufacturing a
 17 commercial reactor vessel. As it turned out, PG&E used the wrong material to weld the
 18 Diablo Canyon Unit 1 nuclear reactor pressure vessel. Because the nuclear industry was
 19 in its infancy, it was not yet known that the material used to weld the Diablo Canyon Unit
 20 1 reactor vessel is highly susceptible to radiation damage. ... Is Pacific Gas and Electric
 frequently inspecting these embrittled welds in the Diablo Canyon Unit 1 reactor as a
 result of this increased neutron embrittlement? No, PG&E does not plan to inspect these
 embrittled welds with increased scrutiny. Normally, each weld of a nuclear reactor is
 inspected every 10 years. (Instead) ... PG&E requested and the NRC approved
 increasing this 10-year inspection interval to 20 years."

21 Thus Arnold Gundersen corroborates Dr. Michael Peck's statement that PG&E is
 22 operating Diablo Canyon outside of its original operating license. Gundersen continues:

23
 24 "By letter dated August 18, 2014, as supplemented by a letter dated March 20, 2015,
 25 Pacific Gas and Electric Company (the licensee) proposed an alternative to the In Service
 26 Inspection (ISI) interval requirements of the American Society of Mechanical Engineers
 27 Boiler and Pressure Vessel Code, Section XI, Paragraph IWB2412, "Inspection Program
 28 B," for Diablo Canyon Power Plant (DCPP), Unit 1. Inspection Program B requires
 volumetric examination of essentially 100 percent of reactor pressure-retaining welds
 identified in Table IWB-2500-1 once each 10- year interval. Pursuant to Title 10 of the
 Code of Federal Regulations (10 CFR), paragraph 50.55a(z) (50.55a(a)(3)(i) at the date
 of application), the licensee requested to use a proposed alternative to extend the DCPP

1 Unit 1 reactor pressure vessel (RPV) inspection interval from 10 to 20 years. ... The U.S.
2 Nuclear Regulatory Commission (NRC) staff has completed its review of the licensee's
3 submittal and, as set forth in the enclosed safety evaluation, concludes that extending the
ISI interval from 10 to 20 years will provide an acceptable level of quality and safety...."

4 NRC regulations require that all the welds in the Diablo Canyon reactor be ultrasonically
5 inspected at least every 10 years. PG&E had previously committed to following the higher
6 testing standards of the American Society of Mechanical Engineers for inspecting the welds to
7 determine if flaws are developing. The current ten-year inspection period was to be completed
8 by the end of 2015. PG&E has thus reneged on its promise to the ASME to remain fully within
their professional judgment.

9 Unit #1 is known as one of the 5 most degraded reactor vessels of any now still operating.
10 "Currently there are 99 remaining nuclear reactors in the United States. Diablo Canyon Unit # 1
11 is one of the 5 most embrittled reactors in the United States."¹⁰

12 PG&E has intentionally chosen to disregard the most important mode of testing the
13 pressure vessel constructed on Unit #1, and which is constructed in a specifically poor manner,
14 which is susceptible to accelerated embrittlement.

15 PG&E is acting with gross criminal negligence to hide the condition of the pressure
16 vessel and core of Unit #1 from the Public, the California Public Utilities Commission, and The
California State Lands Commission.

17 PG&E is known for its "use-until-fail" maintenance policy and PG&E is asking the State
18 of California and the NRC to allow it to operate a facility which has the potential to destroy half
19 of the inhabitable area of California. For 20 years to date, 2005 to 2025, PG&E has been
20 keeping itself in the dark as to whether or not its nuclear reactor is safe, as a willful policy of the
company.

21 Petitioner Paul Kangas requests that the Court enjoin PG&E from operating Unit #1 in
22 order to conduct testing of the stainless steel and to also order testing of the welds in the pressure
23 vessel of Unit #1.

24 This mode of testing must be performed while the reactor is in shut down. At present an
25 extreme danger exists to the population of the State of California. This is a highly technical and
26 arcane issue which petitioner asks the Court to consider.

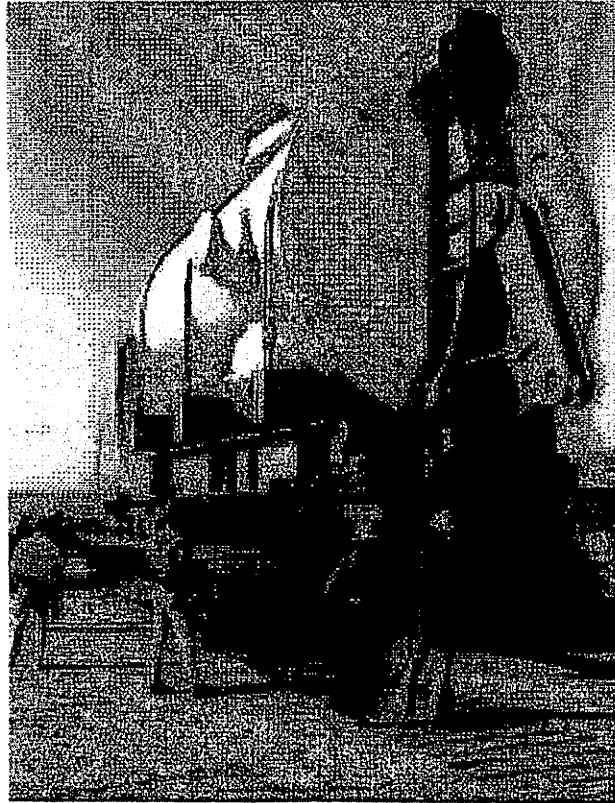
27 ¹⁰ Arnie Gundersen, Fairewinds, testimony to CPUC, January 27, 2017, Appendix A, page 6.
28

The petitioner asks the court to carefully study the written testimony provided by Arnold Gundersen. Petitioner also informs the court that Mr. Gundersen is available to testify in person.

DATED: April 5, 2019

Andrew Paul Kangas
Plaintiff in Pro Se

Neutron Embrittlement at Diablo Canyon Unit 1 Nuclear Reactor



February 15, 1973

The Tribune News

“Workmen at Diablo Canyon hover around a 345-ton reactor vessel as it begins a cautious journey to its final resting place.”¹

Prepared by Fairewinds Associates, Inc

¹ <http://sloblogs.thetribunenews.com/slovault/2010/03/diablo-canyon-reactor-vessel-installed/>

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Executive Summary

1. When Pacific Gas and Electric (PG&E) designed and constructed the Diablo Canyon Atomic Power Plant 50-years ago, it did so without the assistance of a national Engineering and Construction (E&C) firm experienced in designing and constructing atomic power plants, and chose instead to use its own personnel. The first decision PG&E made at the onset was that Westinghouse Electric would supply the atomic reactor and its associated safety systems. When Diablo Canyon Unit 1 was designed 50-years ago, the nuclear corporations supplying these atomic reactors to the utilities knew very little about the reaction of welded steel when it is exposed to high levels of radiation.
2. Diablo Canyon Unit 1 was one of the first US atomic reactors ever designed and manufactured by the nuclear power industry, therefore unusual and consequential errors were made in design and engineering. The wrong material was used to weld the atomic reactor vessel introducing impurities in the weld material itself that have caused significant and accelerated radiation damage in the form of embrittlement to its Unit 1 reactor. Furthermore, the embrittlement caused by the poor weld material has made the atomic reactor vessel in Diablo Canyon Unit 1 among the most dangerously embrittled reactors in country. Diablo Canyon now ranks of one of the worst 5 reactors out of the 99 remaining operational reactors in the US.
3. Reactor embrittlement can cause an atomic reactor to shatter like glass creating what the Nuclear Regulatory Commission (NRC) calls a Class 9 Accident, which is the worst nuclear catastrophe presently acknowledged by the NRC. When the nuclear core leaves the atomic reactor and melts down into the containment, as it did at three of the atomic reactors at the Fukushima Daiichi site in Japan March 11, 2011, the NRC calls each one of these nuclear calamities a Class 9 Accident.

4. The defects in the Diablo Canyon Unit 1 will continue to threaten plant safety as the atomic reactor vessel continues to embrittle. Furthermore, even though it is currently planned that Diablo Canyon Unit 1 will shut down by in 2024,² Diablo Canyon Unit 1 will not operate safely due to its unsound condition, unless a special experimental and untried repair technique is conducted. The procedure is very expensive, and it is questionable whether it could even be successful on the fragile, embrittled and aged atomic reactor.
5. While the repair for such embrittled reactors, called dry recovery annealing, exists in theory, the operation would be very expensive, extremely risky and might prove entirely unworkable.
6. Rather than assuring intensive monitoring of the fragile embrittled reactor vessel, PG&E and the NRC are ignoring its severely degraded condition by allowing Diablo Canyon Unit 1 to continue to operate. PGE requested and in 2015 the NRC granted a waiver of inspection requirements for these critical reactor welds. The previous weld inspection was completed in 2005, but the next series of inspections have been delayed until 2025 as a result of the NRC waiver. This means that for the last 20-years of operation for Diablo Canyon Unit 1, there has not been and there will not be any inspection of these critical welds.

1. What Is Nuclear Reactor Embrittlement and How Does It Develop in An Atomic Reactor?

The earliest radiation studies show that any form of radiation can damage the material with which it comes in contact. This damage is caused when radioactive decay from inside an atomic nucleus emits one of several types of energetic particles that collide with surrounding material. Much like slow moving vehicles in a minor fender-bender, some particles move slowly, have little energy, and cause only a small amount of damage.

² Diablo Canyon Joint Proposal, 16-08-006

However, like an out of control NASCAR wreck, some particles move rapidly, and thus have more energy and therefore cause a great deal of damage.

For atomic power reactors made of steel, the most damaging type of radiation is high energy neutrons released when a Uranium atom fissions (splits).

“Its like billiards,” explains one expert. “Although metal atoms are much heavier than neutrons, when a high energy neutron collides with a metal atom, the neutron forces the atom from its lattice-the geometric array of atoms.”³

The design life for each of the atomic reactors at Diablo Canyon is only 40-years and not the 60 or more years that PGE and the NRC have claimed in the past. Moreover, “irradiation embrittlement” is a “significant” issue for these reactors according to the Electric Power Research Institute (EPRI) documents reviewed by Fairewinds.⁴

Early nuclear reactors, like Diablo Canyon Unit 1, whose reactor was designed and purchased 50-years ago and finally installed in September 1973, contained chemical impurities in their weld material, such as copper, that significantly worsened the neutron damage to the welds. That the copper embedded in the welds of the Diablo Canyon Unit 1 reactor could amplify neutron damage was not understood by designers until after the atomic power reactor vessel had been manufactured and delivered to the site. These copper containing welds could not be removed from the reactor vessel without destroying the reactor itself, which had already been installed at Diablo Canyon Unit 1. Diablo Canyon Unit 2 was manufactured after the nuclear reactor industry identified problems with copper impurity in reactor vessel welds, and the weld materials were corrected by leaving out the copper. Therefore, Diablo Canyon Unit 2 has experienced less embrittlement than Unit 1, which appears due to the elimination of copper in its welds.

Before the industry realized what was happening, which was about 1972, spools of copper coated wires were routinely used for these welds. The

³ *Thermal shock-new nuclear-reactor safety hazard*, Edward Edelson, *Popular Science* June 1983.
<http://static1.1.sqspcdn.com/static/f/356082/25715973/1417195845950/June+1983+Popular+Science.pdf?token=a42WKwrX5fEjMEeVND6FGLOKmwC%3D>

⁴ *Welding and Fabrication Influence on Stress Corrosion Cracking (SCC)*, ATI-CSC-11, Lake Louise, Alberta, Canada, Dana Couch, EPRI, September 29, 2011, slides 13, 14 and 21.

copper was used to prevent rust...Reactor builders switched to nickel coated electrodes, but they couldn't replace the welds in the older reactors...It can take three weeks of repeated passes with electrodes to complete one of those welds. That type of weld, engineered to be a powerful bond between steel sections of reactor vessels, contained enough copper to become a potential hazard instead.⁵

The highest number of neutrons bombarding the nuclear reactor vessel occurs in the middle of the reactor vessel in what is called the vessel "beltline". The "beltline" region, is exactly where the major welds are located and is particularly vulnerable to embrittlement. According to the Nuclear Regulatory Commission,

Reactor pressure vessels, which contain the nuclear fuel in nuclear power plants, are made of thick steel plates that are welded together. Neutrons from the fuel in the reactor irradiate the vessel as the reactor is operated. This can embrittle the steel, or make it less tough, and less capable of withstanding flaws which may be present. Embrittlement usually occurs at a vessel's "beltline," that section of the vessel wall closest to the reactor fuel. Pressurized water reactors (PWRs) are more susceptible to embrittlement than are boiling water reactors (BWRs). ...Steels with a higher proportion of copper and nickel will tend to be more susceptible to embrittlement, than are steels with lower proportions of these two elements....⁶

2. How serious is the neutron embrittlement problem at Diablo Canyon?

Currently, there are 99 remaining operating nuclear reactors in the United States. Diablo Canyon Unit 1 is one of the five most embrittled reactors in the United States. Unit 1 is approaching its regulatory limit for embrittlement, and will exceed that limit on or about the time its original 40-year license expires. According to a Nuclear Regulatory Commission letter dated April 18, 2013⁷ the NRC stated that:

The NRC currently estimates that the following (five) plants will exceed the PTS⁸ screening criteria of 10 CFR 50.61 during their 20-year period of operation beyond their original 40 year licenses ...Diablo Canyon Unit 1.

⁵ IBID

⁶ *NRC Fact Sheet on Reactor Pressure Vessel Issues, Embrittlement*, <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/prv.html>

⁷ *NRC letter to Entergy Nuclear Operations, Inc, April 18, 2013, Subject: Summary of the March 19, 2013, Public Meeting WEBINAR Regarding Palisades Nuclear Plant*

⁸ PTS – Pressurized Thermal Shock

3. When did the State of California become aware of the seriousness of nuclear embrittlement of nuclear reactors?

Four years before Diablo Canyon 1 became operational, in 1981, personnel in the Office of the Governor of California were made aware that nuclear reactor embrittlement with its associated risk of a nuclear reactor failure and radiation leak was a serious problem. Peter H. Gleick, a specialist in the office of Gov. Edmund G. Brown's assistant for energy and environment wrote a Letter to the Editor of the *New York Times* dated in 1981. In that letter, Mr. Gleick said that nuclear reactor embrittlement "...may be the most serious known problem facing existing nuclear power plants... which could cause failure of the pressure vessel containing nuclear fuel." Mr. Gleick's full letter is pasted below.

If The Pressure Vessel Of A Reactor Cracks

To the Editor:

Your Oct. 24 editorial "Brittle Metal and Nuclear Safety" correctly calls attention to what may be the most serious known problem facing existing nuclear power plants - "pressurized thermal shock," which could cause the failure of the pressure vessel containing the nuclear fuel.

Although progressive embrittlement of the pressure vessel has always been anticipated, it now appears that many such vessels will become susceptible to cracking long before reaching their 30- to 40-year lifespan. This problem, however, is neither as avoidable nor as correctable as you suggest.

As you stated, both overcooling and high pressurization must exist before a vessel can crack. Yet there are situations where rapid cooling together with high pressurization is required in order to avoid a serious accident. The operator actions needed to avoid a serious reactor accident may be completely contradictory to those required to avoid cracking the pressure vessels.

For this reason, the Nuclear Regulatory Commission has taken the position that relying on operator action is not an acceptable solution to the risk of pressure vessel failure.

Similarly, the statement that correcting this problem involves catching the flaw early is accurate but misleading. Pressurized thermal shock is a problem that is most severe in the older generation of reactors - those built

before the mid-1970's (newer pressure vessels have better materials characteristics and are less susceptible to embrittlement).

As a consequence, catching the flaw early is not possible for most of these older reactors, which are already close to reaching unacceptable levels of embrittlement. Moreover, the "solution" described in the editorial, annealing of the vessel, requires emptying the entire core of nuclear fuel and heating the highly radioactive pressure vessel to several hundred degrees above its normal operating temperature for a very long period - perhaps up to several months.

Theoretically, the strength of the vessel is then recovered. In practice, however, no commercial nuclear reactor vessel has ever been annealed, and there are serious questions about the time required, the economic costs, the radiation exposure to workers and, in fact, whether or not this process will be successful.⁹

Mr. Gleick's 1981 letter to the New York Times was prescient. One reactor at Yankee Rowe was forced to shut down in 1992 due to embrittlement problems, while others, such as Palisades in Michigan and Diablo Canyon Unit 1, are continuing to experience serious embrittlement problems that increase risk and shorten each plant's operating life. Still, 36 years after the letter was written, no operating reactors in the US or Europe have ever been shut down and re-annealed due to the technical risks involved in that process.

4. What are the safety consequences of an embrittled nuclear reactor?

Each nuclear reactor vessel is designed to contain the radioactive nuclear fuel in its reactor core, so the reactor vessel must hold water in order to cool its radioactive fuel in the event of a nuclear calamity. First and foremost, the NRC makes the mathematical assumption that the atomic reactor vessel will maintain its strength during every accident or mishap scenario analyzed by Pacific Gas and Electric for the Diablo Canyon plants. If the reactor vessel were to crack open due to neutron embrittlement, all the nuclear power plant's critical safety systems will fail, leading to a catastrophic release of radiation.

⁹ *New York Times*, November 7, 1981 <http://www.nytimes.com/1981/11/07/opinion/1-if-the-pressure-vessel-of-a-reactor-cracks-084005.html>

The NRC and nuclear industry experts have long recognized the seriousness of reactor embrittlement and the radiation release consequences for the public should that failure occur. In 1982, Demetrios L. Basdckas, an NRC Reactor Safety Engineer, expressed his concerns and frustrations in his letter to the editor, also published in the New York Times:

“There is a high, increasing likelihood that someday soon, during a seemingly minor malfunction at any of a dozen or more nuclear plants around the United States, the steel vessel that houses the radioactive core is going to crack like a piece of glass. The result will be a core meltdown, the most serious kind of accident, which will injure many people, and probably destroy the nuclear industry with it”¹⁰

5. How does nuclear reactor embrittlement lead to the failure of the reactor?

If the nuclear reactor were to suddenly shut down during one of dozens of atomic power mishaps that nuclear reactor design engineers and the NRC anticipate will happen, the safety system would immediately inject cool water into the reactor vessel in an attempt to cool the reactor core in hopes of preventing a meltdown. However, in a seriously embrittled reactor like Diablo Canyon I, when that cool water is injected and comes in direct contact with the hot reactor vessel, it can cause what is called “Pressurized Thermal Shock” (PTS), and the 8-inch steel thick reactor vessel can crack causing it to break open and release massive amounts of radioactivity into the surrounding area and the environment. While no atomic reactor mishap, or accident as the industry names them, should be called “routine”, this sequence of rapid cooling and sudden pressurization can cause what the NRC and nuclear industry term a “routine accident” to become a radioactive disaster.

Another reason reactor vessel embrittlement is more of a concern for PWRs is because PWRs may experience pressurized thermal shock (PTS). PTS can occur under some accident scenarios that introduce cold water into the reactor vessel while the vessel is pressurized. Introduction of cold water in this manner can cause the vessel to cool rapidly, resulting in large thermal stresses in the steel. These thermal stresses, along with the high

¹⁰ *New York Times*, March 29, 1982

internal pressure and an embrittled vessel, could lead to cracking and even failure of the vessel.¹¹

There have been several historical precursor sequences that prove that abrupt temperature and pressure changes can and do occur at operating nuclear power plants. The first such precursor event happened at California's Rancho Seco atomic power reactor on March 20, 1978. When a worker dropped a light bulb, it in turn caused a cascade of electrical faults. Instruments in the control room went haywire leaving the reactor operators with no accurate instrumentation to rely upon while attempting to control the reactor. The temperature inside the reactor dropped from 582 to 285 in one hour. The reactor pressure dropped from 2,200 psi to 1,600 psi. Then, when cold water was injected, the reactor pressure jumped back over 2,000 but at a low temperature.

The Rancho Seco "transient", as nuclear engineers call it, was a near miss that made it clear that pressurized water reactors are susceptible to abrupt changes in temperature and pressure. While the nuclear reactor welds were severely stressed by the pressure and temperature changes, the Pressurized Thermal Shock (PTS) and nuclear vessel failure was avoided at Rancho Seco, which was a new reactor, so its welds were not yet subject to embrittlement by long-term neutron bombardment, like Diablo Canyon or the Palisades reactor in Michigan.

Unfortunately, Diablo Canyon Unit 1 is particularly susceptible to a similar PTS (Pressurized Thermal Shock) near miss like the one that was previously experienced at Rancho Seco for two reasons. First, Diablo Canyon is one of the most embrittled reactors in the United States. Second, its location, in the most seismically active area of the United States, means that it is more likely to experience a very destabilizing seismic event which blinds the operators from the temperature of the reactor vessel in a similar manner to the conditions encountered at Rancho Seco.

This is not to say that an earthquake would necessarily crack the reactor. Rather, the earthquake would cause a sudden emergency shutdown that could defeat most safety

¹¹ *NRC Fact Sheet on Reactor Pressure Vessel Issues, Embrittlement*, <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/prv.html>

systems, cause control room instruments to become unreliable because of “instrument chatter” (<http://www.fairewinds.org/nuclear-energy-education/whose-fault?rq=chatter>), and thus provide the control room operators with little or no accurate data about the temperature and pressure in the reactor. It is this lack of accurate operator data that is one of the hallmarks of both the Rancho Seco mishap and the triple meltdown disaster at Fukushima Daiichi.

In the hours immediately after a seismic emergency induced shutdown at Diablo Canyon Unit 1, atomic reactor operators, acting without accurate information, may mistakenly inject cold water at the wrong time, inducing PTS (Pressurized Thermal Shock) in the old embrittled Diablo Canyon reactor vessel. The net effect would be catastrophic cracking of the reactor vessel causing the release of its uncooled atomic fuel rods onto the floor of the containment building in a similar fashion to the disaster at the three Fukushima Daiichi reactors. All three Fukushima Daiichi atomic reactors cracked open and spilled their radioactive contents in meltdowns that are still ongoing.

More recent analyses now show that the atomic reactor vessel can crack even when it is not under pressure. Hence, the damage from what the industry has called “pressurized” thermal shock is now clearly understood as simply damage from thermal shock.

According to the NRC’s Advisory Committee on Reactor Safeguards as recently as 2014¹²:

Mr. Kirk: well, they're - and that's one of the - in fact, that was very much a surprise because in the - in the early analysis - in the 1980s analysis the no-pressure events were a priori screened out.

But what we found in running the calculation is you can run a crack pretty much all the way through the wall.

Member Skillman: just with temperature.

Mr. Kirk: just with temperature.

Member Skillman: just with temperature.

Mr. Kirk: yes.

¹² Advisory Committee on Reactor Safeguards, top of p.33, Oct. 16, 2014 transcript

6. What is Nil-Ductility Transition Temperature and why is it important?

In order to prevent catastrophic PTS induced reactor vessel failure in old reactors including Diablo Canyon Unit 1, administrative controls have been implemented to assure that control room operators are sure that the nuclear reactor is very hot before it is significantly pressurized. As the reactor ages and becomes more embrittled, the temperature must be increased higher and higher prior to increasing pressure in the vessel. The temperature that must be reached before pressure inside the vessel may be applied is called Nil-Ductility Transition Temperature. Above this Nil-Ductility Transition Temperature, the nuclear reactor is ductile (i.e. more flexible) and will not crack. Below this temperature, the vessel is not ductile and will crack if the pressure is increased. If pressure is increased at too low a temperature, the vessel can crack, hence the term “nil-ductility transition temperature.” Each year as the nuclear reactor vessel ages, it becomes more embrittled causing the temperature necessary to assure Nil-ductility in the reactor vessel to increase.

It is disturbing to note that the *alleged* “solution” created by the NRC and Pacific Gas & Electric to protect Diablo Canyon Unit 1 against its increasing neutron embrittlement, is simply to create administrative controls that require Diablo Canyon atomic reactor operators to implement during a reactor emergency. These administrative controls require the reactor operators to raise the temperature of the reactor prior to increasing the pressure. This is analogous to being aware that the brakes on a tractor-trailer will fail at speeds above 50 miles per hour. Rather than fix the brakes, the administrative solution would be to insist that the truck driver never exceed 49 miles per hour. Just as reactor vessel embrittlement gets significantly worse over time, bad brakes on the truck would demand that the driver would reduce his speed further every year, rather than simply make the necessary mechanical repair to the brakes.

Rather than fix its aging embrittled atomic reactor vessel, PG&E’s strategy for Diablo Canyon Unit 1 is to repeatedly modify its mathematical calculations so that operators use an ever higher nil-ductility transition temperature in PG&E’s attempt to stretch the life of its embrittled reactor vessel until its projected shutdown in 2024. Since 2001, nuclear

industry experts such as Odette and Lucas continue to acknowledge that the service life of old atomic reactors is limited by embrittlement.

Neutron irradiation embrittlement could limit the service life of some of the reactor-pressure vessels in existing commercial nuclear-power plants.... embrittlement remains a potential issue for some older vessels, and is an unknown for the extended life of others.¹³

7. How accurate is the science of predicting the extent of atomic reactor neutron embrittlement and is it really feasible to significantly extend the “useful life” of an atomic reactor based upon such modified calculations?

It is technologically impossible to measure the actual condition of the embrittled reactor vessel at Diablo Canyon without cutting into the vessel itself in search of metallurgical samples, and destroying the vessel by that process. So, instead of cutting into the vessel itself, engineers make estimates of the condition of the reactor vessel metal. These estimates of the “useful life” of an embrittled reactor have many mathematical uncertainties that engineers call “variables”. The following excerpt from a 2001 paper on reactor vessel embrittlement is provided [with emphasis added] to give the reader a brief sampling of the complexity of the embrittlement calculation:

Measurements of fracture toughness (e.g., K_{Ic}) require **special specimens and relatively sophisticated test procedures that were not available at the time surveillance programs were first implemented...** The T_{ndt} is the so-called the **nil-ductility transition temperature for the unirradiated steel, which is determined using a rather complex procedure**, generally based on either Charpy or drop weight tests. In irradiated steel, the $K_{Ic}(T - T_{ndt} - DT_i)$ curve is shifted up in temperature by the DT_i , which includes a margin term. While showing a great deal of early foresight, **this procedure is somewhat arcane and often lacks a rigorous physical justification... Plant-specific surveillance data are usually not sufficient to predict DT_i .** More commonly, the DT_i are evaluated using regulatory equations based on a large collection of surveillance data from many plants. **...Predictive models must also account for strong synergistic interactions between variables, such as**

¹³ *Embrittlement of Nuclear Reactor Pressure Vessels*, G.R. Odette and G.E. Lucas, 2001, *The Minerals, Metals & Materials Society*, <http://www.tms.org/pubs/journals/jom/0107/odette-0107.html>

* Note: G.R. Odette and G.E. Lucas are professors in the Department of Mechanical and Environmental Engineering at the University of California, Santa Barbara.

copper nickel... Because of the number of variables and variable combinations (e.g., Cu-Ni- Φ - Φ t-T_i, T_a, t_a), coupled with various limitations in the surveillance and PIA databases, purely empirical DT_i predictions are unreliable particularly when extrapolated to conditions beyond the existing variable range (e.g., higher Φ t)... Despite progress in predicting irradiation embrittlement and recovery, a number of issues are not fully resolved or quantified... Perhaps the most difficult issue is associated with material variability and the inherent uncertainties about the composition and properties of the steels in the RPV itself. ... (Embrittlement assumptions) rests on a series of empirically based assumptions and faces a number of challenges related to its application to assessing the integrity of irradiated pressure vessels. Issues regarding the key assumptions include the validity of a universal master-curve shape as well as both statistical and constraint-mediated size effects. Issues associated with the use of the master-curve method in integrity assessments include the applicability to dynamic and arrest toughness, effects of irradiation on the master-curve assumptions, ties to the Charpy-based surveillance database, effects of realistic surface/shallow flaw configurations, and the reliability of data from archival-surveillance materials to represent actual vessel steels.¹⁴

Clearly, the process of determining the Nil-ductility transition temperature is not an exact science. A paper written by Nikolaeva, Nikolaev, et al in 2000 supports Fairewinds' assessment of uncertainty and complexity in the development of the embrittlement calculations:

The radiation embrittlement of reactor vessel materials is a **complex process**, which depends upon the conditions of a radiation in the microstructure and chemical composition of the steel. It is universally acknowledged that phosphorus, copper, nickel intensify the radiation embrittlement of vessel material the most.... **The presence of a synergistic interaction of elements in the irradiation process and the complex interaction of metallurgical factors and the radiation conditions make it difficult to determine the degree to which impurities and alloying elements influence radiation embrittlement.**¹⁵

The process of using engineering analysis to extend the "useful life" of embrittled nuclear reactors has the net effect of reducing the safety margin of those reactors. A paper

¹⁴ <http://www.tms.org/pubs/journals/jom/0107/odette-0107.html>

Embrittlement of Nuclear Reactor Pressure Vessels, G.R. Odette and G.E. Lucas, 2001, *The Minerals, Metals & Materials Society*

¹⁵ Embrittlement of Low-Alloy Structural Steel by Neutron Irradiation, Atomic Energy, Vol. 88, No.4, 2000: Nikolaeva, Nikolaev, Kevorkyan, Kryukov & Korolev, <http://link.springer.com/article/10.1007%2FBF02673611#page-2>

written in 2000 by the Nuclear Energy Agency Nuclear Science Committee states that safety margins will be reduced by extending the “useful life” of embrittled reactors [Emphasis added]¹⁶

As many commercial light water reactors begin to approach the end of their licensed lifetime, nuclear utilities have started to investigate the possibility of extending the operating life of reactors beyond the originally licensed 30-40 years. **Longer reactor operating times mean higher neutron and gamma fluence levels and/or smaller safety margins ...** High energy neutron bombardment degrades the structural integrity of RPVs.

In 1981, Robert Pollard, of the Union of Concerned Scientists, was one of the first scientists in the world to identify the danger and the degree of uncertainty in embrittlement calculations within the scientific community.¹⁷

“If you really want a good fight, ask people about the reliability of those safety estimates. **The method the NRC and the industry uses is called probabilistic risk assessment. Its designed to get around a rather impressive lack of concrete evidence...** In a probabilistic risk assessment, you estimate the likelihood of an event that initiates a transient, then estimate the likelihood of the reaction to that event, the reaction to that reaction, and so on down the line. Westinghouse, for example, has a model that starts with 17 possible initiators and runs through event trees to more than 8,200 end points... But there are inevitable differences of opinion about the value of those calculations... Not everyone agrees with the calculations. **“The NRC may consult its Ouija board and come up with a number”, says Robert Pollard of the Union of Concerned Scientists, “but the error bands are so large that it is essentially useless.”** ... “There’s no dispute that current emergency systems would not be able to cope with the fracture of the reactor vessel... The defense in depth argument disappears when you talk about pressurized thermal shock.” [Emphasis Added]

Dr. George Sih, Director of Fracture and Solid Mechanics at Lehigh University, echoed the Union of Concerned Scientists sentiments stating:¹⁸

¹⁶ PREDICTION OF NEUTRON EMBRITTLEMENT IN THE REACTOR PRESSURE VESSEL, Nuclear Energy Agency Nuclear Science Committee, 2000 <https://www.oecd-nea.org/science/docs/2000/nsc-doc2000-5.pdf>

¹⁷ *Thermal shock-new nuclear-reactor safety hazard?* Edward Edelson, *Popular Science*, June 1983, <http://static1.1.sqspcdn.com/static/f/356082/25715973/1417195845950/June+1983+Popular+Science.pdf?token=a42WKwrX5fEjMEeVND6FGLOKmwC%3D>

¹⁸ IBID

...the (NRC fracture) report is built on a foundation of sand. "The samples are five inches long, and the vessel is 500 inches long," Sih said. "The sample is very thin, and the vessel is eight inches thick. We don't know how to transfer small-sample data to the design of large-scale structural components. [Emphasis Added]

8. Is it even feasible to repair an embrittled nuclear reactor?

When a nuclear reactor is first constructed in a dedicated manufacturing facility, many curved steel plates are welded together, almost like staggering bricks while laying a brick wall. Rather than placing cement between each brick, the curved plates are welded together.

The initial heat from welding these steel plates together causes stresses in the reactor vessel that must be eliminated prior to operating the atomic reactor. When the reactor is vessel is completely fabricated, it is heated in a process called "annealing", which occurs in the manufacturing facility in order to eliminate the original welding induced stresses.

In metallurgy, annealing is a heat treatment that alters the physical and chemical properties of the steel to increase its ductility, in order to improve the machinability of steel to make it more workable by softening the steel. Annealing also enhances the toughness of steel, improves its homogeneity, and refines the grain size of the steel. Annealing is a process by which steel is heated to a specific temperature and then allowed to cool very slowly. In reactors, this process usually takes about 168 hours, but that depends on where the reactor was made and what metal was mixed with the steel. After annealing, the reactor vessel is considered stress free and ready to be installed at the reactor site.

Once operational, the process of neutron embrittlement causes new stresses to build up as the reactor ages. Eventually, if no physical changes are made, the reactor will crack due to these stresses. In order to eliminate any of these new neutron embrittlement stresses created during reactor aging, the reactor must be re-annealed in place at the reactor site.

The initial annealing of the vessel at the manufacturing facility is a relatively straight forward process, however re-annealing a 40-year-old irradiated, embrittled reactor inside the nuclear containment building with additional pipes and wires attached is extraordinarily difficult.

Engineers were surprised when reactors began to become brittle and so fragile that they could shatter while under the duress of operating. According to Reijo Pelli and Kari Törrönen in *State-Of-The-Art Review On Thermal Annealing*¹⁹:

“Radiation embrittlement in some pressurised water reactors has been so fast that, in spite of other applied mitigation methods, thermal annealing has been practically the only solution permitting further operation... In cases where the whole fuel core zone area of the reactor pressure vessel is to be annealed, **a fully successful annealing has yet to be convincingly proven. High thermal stresses may make the thermal treatment troublesome to carry out. (Emphasis Added)**

The process of repairing an embrittled nuclear reactor is called “recovery annealing” sometimes shortened to “re-annealing” and involves heating the nuclear reactor to a temperature much higher than that at which it normally operates in an attempt to allow the embrittlement stresses within the steel nuclear reactor to reduce as the steel softens. Recovery annealing can take two forms: wet and dry. In wet recovery annealing, the nuclear fuel is removed and the nuclear reactor is reheated with water inside to temperatures several hundred degrees higher than its normal operating range. There are approximately 450 reactors currently operating worldwide, and 13 Soviet reactors of the VVER 440 design have been wet annealed during the recovery annealing process. There is a significant difference between the Soviet and Western nuclear reactor designs as well as the character and quality of the steel because the Soviet steel contains more copper. Therefore, wet recovery annealing is not possible in the Western designed and fabricated Pressurized Water Reactors (PWRs).

¹⁹ European Network on Ageing Materials Evaluation and Studies, Espoo, March 1995, VTT Manufacturing Technology, P.O. Box 1704, FIN-02044 VTT, Finland.
<http://capture.jrc.ec.europa.eu/sites/capture/files/files/documents/eur16278en.pdf>

Dry recovery annealing is more complicated because it involves removing the nuclear fuel, all of the water, and all of the highly radioactive internal core structures from the reactor and then applying heat directly to the highly radioactive walls of the reactor. This technique has never been tried in an operating embrittled reactor. According to the International Atomic Energy Agency publication *Thermal Annealing of Reactor Pressure Vessels Is a Needed Mitigation Option*²⁰:

- Dry anneals are performed at higher temperatures than wet anneals
 - Use air as the heating medium inside of radiant can
 - Electric-resistance heating source
- Dry annealing requires removal of core internal structures and primary water so that a radiant heating source can be inserted near the vessel wall to locally heat the embrittled beltline region
 - **Engineering difficulties of dry anneal process are quite complex and may need plant-specific evaluations to assure that other portions of the plant (eg., concrete) are not harmed by the high annealing temperatures. [Emphasis Added]**

The Department of Energy has performed only one dry annealing simulation, [yes, a simulation, not an actual annealing or recovery annealing process], and that was back in 1996 on the Marble Hill reactor vessel in Indiana, a reactor that was abandoned before it ever began operating, thus it was not radioactive and the steel was not embrittled²¹.

In fact, an Annealing Demonstration Project (ADP) funded jointly by the U.S. Department of Energy and the nuclear industry was performed at the uncompleted Marble Hill nuclear plant in Indiana in 1996/1997 The Marble Hill RPV was a four-loop PWR with nozzle supports and designed by Westinghouse. The Marble Hill plant was a partially completed plant but the vessel was in place which allowed for a prototypic annealing demonstration to be executed....

The method used was a dry annealing procedure with an indirect gas-fired method through a heat exchanger. The RPV was instrumented with strain gages and thermocouples to assess strain levels and temperatures over the entire RPV, including nozzles, during and after the annealing operation.

²⁰ *Thermal Annealing of Reactor Pressure Vessels Is a Needed Mitigation Option*, IAEA, November 8, 2013 IAEA, Vienna, Austria, Slide 10
https://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-11-05-11-08-TM-NPE/38.Server_USA.pdf

²¹ Oak Ridge National Laboratory: Reactor Pressure Vessel Task of Light Water Reactor Sustainability Program: Initial Assessment of Thermal Annealing Needs and Challenges, Section 2.2,
<http://info.ornl.gov/sites/publications/Files/Pub32884.pdf>

Currently there are 99 operating reactors in the U.S., while another 20 have been prematurely shutdown and more than 100 were cancelled while under construction. While Diablo Canyon Unit 1 is fast approaching embrittlement limits, no attempts to repair embrittlement problems at any of the U.S. reactor fleet have even been attempted. One U.S. reactor was so seriously embrittled (Yankee Rowe) that its owner decided to permanently terminate its operating license and shut the reactor down rather than attempt a repair. According to the International Atomic Energy Agency (IAEA)²², **“Thermal Annealing Generally is Considered a Last Resort Embrittlement Mitigation Method”**. [Emphasis Added]

9. Is Pacific Gas and Electric frequently inspecting these embrittled welds in the Diablo Canyon Unit 1 reactor as a result of this increased neutron embrittlement?

No, PGE does not plan to inspect these embrittled welds with increased scrutiny. Normally, each weld of a nuclear reactor is inspected every 10 years. However, PGE requested and the NRC approved increasing this 10-year inspection interval to 20 years.

By letter dated August 18, 2014, as supplemented by letter dated March 20, 2015, Pacific Gas and Electric Company (the licensee) proposed an alternative to the inservice inspection (ISI) interval requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section XI, Paragraph IWB-2412, "Inspection Program B," for Diablo Canyon Power Plant (DCPP), Unit 1. Inspection Program B requires volumetric examination of essentially 100 percent of reactor pressure-retaining welds identified in Table IWB-2500-1 once each 10-year interval. Pursuant to Title 10 of the *Code of Federal Regulations* (10 CFR), paragraph 50.55a(z) (50.55a(a)(3)(i) at the date of application), **the licensee requested to use a proposed alternative to extend the DCPP Unit 1 reactor pressure vessel (RPV) inspection interval from 10 to 20 years. ...** The U.S. Nuclear Regulatory Commission (NRC) staff has completed its review of the licensee's submittal and, as set forth in the enclosed safety evaluation,

²² *Thermal Annealing of Reactor Pressure Vessels Is a Needed Mitigation Option*, IAEA, November 8, 2013 IAEA, Vienna, Austria, Slide 2
https://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-11-05-11-08-TM-NPE/38.Server_USA.pdf

concludes that **extending the ISI interval from 10 to 20 years will provide an acceptable level of quality and safety....**²³ [Emphasis Added]

Previously, regulations required that all the welds in the Diablo Canyon reactor would be ultrasonically inspected at least every 10-years, with the latest ten-year inspection period to be completed by the end of 2015. PGE had previously committed to follow the requirements of the American Society of Mechanical Engineers for inspecting these welds to determine if any flaws were developing.

The ultrasonic technique for atomic power reactors is a process similar to that of an ultrasonic sonogram during pregnancy. Despite knowing that Diablo Canyon Unit 1's weld copper content is unacceptably high, and despite knowing that Diablo is one of the five most embrittled reactors in the United States, the NRC has allowed PGE to delay these critical weld inspections for 10 more years, until 2025. This prevents analysis by the public and by regulators of critical information determining that the reactor should be shut down sooner rather than the Diablo Canyon Retirement Joint Proposal date of 2024. It appears that the NRC is assisting PGE by withholding this critical weld embrittlement data until the aging Diablo Canyon reactor is no longer in operation.

10. If Diablo Canyon were to attempt a recovery annealing of its embrittled nuclear reactor, what would be the cost, risk and duration of the repair?

If Diablo Canyon continues to operate, the reactor will become so embrittled and damaged that embrittlement repair will necessitate using the yet untried dry recovery annealing technique. As a result, Pacific Gas and Electric (PG&E) will incur significant risks, large out of pocket expenses, and a long outage delay, *if the plant is ever able to actually restart*. The capitalized cost for the repair contractor's equipment and expertise alone will be at least \$45,000,000 and may turn out to be as high as \$100,000,000, according to a study conducted by Carnegie Mellon University. The data reviewed by

²³ *Diablo Canyon Power Plant, Unit No. 1 - Request For Alternative RPV-U1-Extension To Allow Use of Alternate Reactor Inspection Interval Requirements*, NRC Approval Letter to PGE, June 19, 2015. <http://pbadupws.nrc.gov/docs/ML1516/ML15168A024.pdf>

Carnegie Mellon also shows that the duration of the repair outage would be approximately 11 months and might even last as long as two years.

A process called annealing might resolve the RPV issue. With annealing, the entire RPV is raised to high temperatures for a duration of time to renew any weak or brittle welds. At the time, this process had never been performed in the United States. **The annealing process would require the facility to be off-line for no less than six months, and possibly much longer, resulting in lost generation sales. Moreover, without a proven annealing process prior to shutdown, the annealing process could be a failure,**

leading to permanent shutdown and decommissioning. This issue represented the single largest liability to the continued operation of the nuclear power facility.

Aside from the possibility of permanent shutdown, because the length of time that the plant would be offline is unknown, **the technical uncertainty creates an economic exposure in the project. The longer the plant is shut down, the greater the economic loss. [Emphasis Added]**

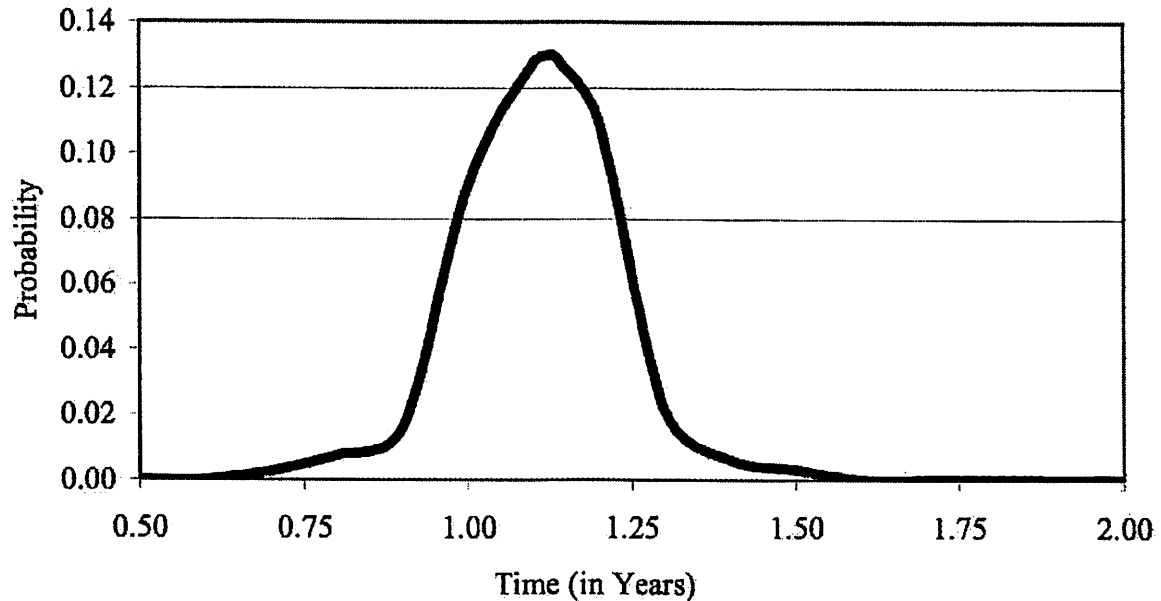
The combinations of the above uncertainties and the timing at which they could occur require that a rational decision-making process be integrated into the model. Obviously, future decision would greatly influence the plant's cash flows. For example, if eight years into the future, the NRC requires that annealing be done or the plant shutdown permanently, then the plant owner must decide what to do. At the time of the decision, does annealing make economic sense? At that future decision point, the expected future earnings of the plant and the expected cost of annealing must be compared to the cost of retiring the plant.

The expected value associated with plant shutdown (because of RPV embrittlement) is calculated by determining the shortfall in the decommissioning account for each year and then discounting this amount into the appropriate year's dollars... **The cost of repairs is assumed to average approximately \$45 million ... and an upper limit of \$100 million ... It is also assumed that the repairs will require the plant to be down for an average of 11 months. The shutdown time is modeled using a general probability distribution ranging from 6 months to two years (see Figure 5). [Emphasis Added]**²⁴

²⁴ *Monte Carlo Methods for Appraisal and Valuation: A Case Study of a Nuclear Power Plant, 2001*, Carnegie Mellon Electricity Industry Center CEIC Working Paper 02-01 (pages 16-19)

<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.8.7026&rep=rep1&type=pdf>

Figure 5: Probability Distribution of the Length of Time Needed to Anneal



Unfortunately, the Carnegie Mellon study did not analyze the additional financial impact of licensing schedule delays, which is a significant risk to a potential Diablo Canyon embrittlement repair project of recovery annealing and the extensive license application process determined by the NRC.

There are very strict protocols that both PG&E and Diablo Canyon have to follow along with the NRC to even consider the recovery annealing process, according to 10 CFR § 50.66:

§ 50.66 Requirements for thermal annealing of the reactor pressure vessel.

- (a) For those light water nuclear power reactors where neutron radiation has reduced the fracture toughness of the reactor vessel materials, a thermal annealing may be applied to the reactor vessel to recover the fracture toughness of the material. The use of a thermal annealing treatment is subject to the requirements in this section. **A report describing the licensee's plan for conducting the thermal annealing must be submitted in accordance with § 50.4 at least three years prior to the date at which the limiting fracture toughness criteria**

in § 50.61 or appendix G to part 50 would be exceeded. Within three years of the submittal of the Thermal Annealing Report and at least thirty days prior to the start of the thermal annealing, the NRC will review the Thermal Annealing Report and make available the results of its evaluation at the NRC Web site, <http://www.nrc.gov>. **[Emphasis Added]**²⁵

Because recovery annealing is a significant change to a plant's operating license, federal statute requires that the Nuclear Regulatory Commission complete a 10 CFR §50.59 safety review that requires full public participation in the licensing process. Active public participation in such a license change would be highly likely in California, which could stop or delay the project for many years. According to the International Atomic Energy Commission, fear of public participation in an extended licensing process prevented the embrittled Palisades reactor from attempting the recovery annealing process:

Why the Demonstration? – Palisades NPP

- Palisades was limited to operate until 1999 based upon PTS concerns for the most-limiting weld metal heat (W5214 axial welds); other welds: 27204
- Planned to anneal in 1998 to recover properties and continue operation to at least 2011 and hopefully beyond
- **Annealing canceled due to revised fluence estimates; also concern about public hearings when authorized to anneal**²⁶ **[Emphasis Added]**

Conclusion

The neutron embrittlement problems at Diablo Canyon Unit 1 are some of the most serious in the United States. Unit 1 has been operating for more than three decades, and every year that passes increases the embrittlement risks. The continued operation of this

²⁵ 10 CFR § 50.66

²⁶ https://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-11-05-11-08-TM-NPE/38.Server_USA.pdf

embrittled reactor in a location known for its seismicity presents safety risks unlike any other reactor in the United States.

While, it may be technically feasible to reduce the current embrittlement problems at Diablo Canyon by a recovery annealing of the reactor vessel using the “dry” annealing technique, there are two serious obstacles with this process. *First*, this is a process that has never been attempted on a U.S. reactor and may not be successful, and *second* there are serious risks and substantial costs that will be incurred with absolutely no guarantee that those costs will ever be recovered during the remaining *possible* operating life of these reactors.

Ultimately, the evidence reviewed that PG&E’s continued operation of Diablo Canyon Unit 1 in such an embrittled and degraded condition is a real risk to public safety.